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How global is the global effect? The spatial characteristics of saccade averaging

S. Van der Stigchel [a,*], T.C.W. Nijboer [a,b]

[a] Experimental Psychology, Helmholtz Institute, Utrecht University, Utrecht, The Netherlands

[b] Rudolf Magnus Institute of Neuroscience and Centre of Excellence for Rehabilitation Medicine, University Medical Centre Utrecht and Rehabilitation Centre De Hoogstraat, Utrecht, The Netherlands

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ABSTRACT

When a target and a distractor are presented in close proximity, an eye movement will generally land in between these two elements. This is known as the 'global effect' and has been claimed to be a reflection of the averaged saccade programs towards both locations. The aim of the present study was to systematically investigate whether there is only a limited area in the saccade map in which saccade averaging occurs. To this end, we examined various distances between target and distractor in two experiments and investigated whether the majority of eye movements landed in between the target and the distractor. Results indicated that the endpoint distribution was unimodal for distances up to 35° (in polar coordinates), with saccades generally landing in between the target and the distractor. When the distance was higher than 45°, the saccade endpoint distribution was predominantly bimodal, with saccades landing either on the target or on the distractor. The decrease in saccade averaging was linear until almost no averaging saccades were observed for the longest distances. As saccades landing in between target and distractor reflect a weak, or absent, top-down signal, the present study indicated that top-down information is unable to strongly influence the oculomotor system when target and distractor are presented in close proximity. In this situation, the resulting eye movement is determined by the weighted average of saccade vectors present in a restricted region in the motor map.

1. Introduction

When we execute an eye movement to bring an area of interest in a scene to the high-acuity fovea, the endpoint of the eye movement is a reflection of the competition that has preceded saccade initiation. This competition is caused by the fact that we can only execute one eye movement at time. Because of this restriction, there is a continuous competition between top-down and bottom-up information during the selection of the next eye movement program. For instance, although our top-down aim might be to look at the clock in our room, the entrance of a colleague in the room might cause the eyes to be directed to the door due to the strong bottom-up information evoked by this event.

One of the paradigms that has proven to be sensitive to this oculomotor competition is the oculomotor distractor paradigm (Theeuwes et al., 1998; Walker et al., 1997). In this paradigm, a target and a distractor element are presented simultaneously. In this situation, the eyes are sometimes erroneously directed to the distractor location due to the strong bottom-up signal evoked by the presentation of the distractor. In this case, the top-down aim to select the target location as the location for the subsequent eye movement is overridden by the distractor information.

In the oculomotor distractor paradigm, the target and distractor are generally presented far apart and it is easy to disentangle whether the eye movement was initiated to the target or to the distractor. Interestingly, however, when the target and distractor are presently in close proximity, the endpoint is generally positioned in between the two elements, a phenomenon known as the 'global effect' (Findlay, 1982; Van der Stigchel, Heeman, & Nijboer, 2012) (for reviews see, Van der Stigchel & Nijboer, 2011; Vitu, 2008). The global effect has been explained in terms of a weighted average of activity in the saccade map (Findlay, 1982; Findlay & Walker, 1999; Godijn & Theeuwes, 2002; Meeter, Van der Stigchel, & Theeuwes, 2010; Van Opstal & Van Gisbergen, 1989). In this (retinotopic) saccade map, possible saccade goals are represented by peaks of activity and lateral interactions between locations within the saccade map determine when and where the eyes move. Within the map, connections are assumed to be mainly inhibitory, except for shorter connections which are claimed to be excitatory (see e.g., Munoz & Istvan, 1998). With a short distance between two possible saccade goals, the local spread of excitatory activity results in a strong peak at an intermediate location between the saccade goals. In this situation, the weighted average is therefore assumed to be positioned in between these two stimuli. As the saccade endpoint

* Corresponding author. Address: Experimental Psychology, Helmholtz Institute, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands. Fax: +31 30 253 4511.
E-mail address: S.VanderStigchel@uu.nl (S. Van der Stigchel).

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is determined by the weighted average of the activity in the saccade map on the moment the eye movement is initiated, the eyes will therefore be initiated to a location in between two stimuli. Furthermore, these models predict that saccade latencies for averaging saccades will be reduced due to the quick build-up of activity at the intermediate location. Evidence for the weighted average account comes from studies which have indicated that the endpoint is positioned more towards the larger stimulus (Findlay, 1982), the more salient stimulus (Deubel, Wolf, & Hauske, 1984) or the most dissimilar stimulus (Deubel et al., 1988). As the global effect appears to be reflection of the 'average' of the eye movement programs towards the two elements, this phenomenon is also referred to as 'saccade averaging'.

There is evidence which suggests that saccade averaging can be influenced by higher-order signals, like task instructions. For instance, He and Kowler (1989) showed that saccades were biased towards the most likely target location, regardless of where the target was actually presented. Also, when the generation of accurate saccades is a task requirement, the global effect can be completely abolished or modulated (Findlay & Blythe, 2009; Findlay & Kapoula, 1992). These results suggest that, although saccade averaging is a default option when no task instruction is provided, higher-order signals are able to modulate the extent of the averaging of saccades.

One of the characteristics of the global effect is that it only appears to occur when two elements are presented in relatively close proximity. For instance, Ottes, van Gisbergen, and Eggermont (1984) observed saccade averaging when the distance between both stimuli was 30° in polar coordinates, whereas a bimodal response pattern was observed when the distance was large (90°). This bimodal response pattern indicates that eye movements were executed to either of the two elements, but did not land in between the two stimuli. This conclusion was similar to the results of a study by Walker et al. (1997) who showed that the distractor should be presented within ±20° of the target axis for the endpoint of saccades towards the target to be influenced. Outside this zone, the endpoint of the saccade was not affected but there was an increase in saccade latency which was not observed when the target and distractor were spatially proximal (see also, Chou, Sommer, & Schiller, 1999; Van der Stigchel & Theeuwes, 2005). This increase in saccade latency has been explained by the inhibitory connections in the saccade map between remote locations, attenuating the activity at the target location when an additional distracting element is presented (e.g., Olivier, Dorris, & Munoz, 1999). Therefore, there appears to be only a limited area in the saccade map in which saccade averaging occurs, as the weighted average appears to be based on a restricted region in the motor map.

In contrast to these findings, various recent studies have shown a deviation of the saccade endpoint towards the distractor when this distractor was presented outside the restricted zone in which saccade averaging has been claimed to occur (i.e. even for a distance between the two stimuli of 45°, Arai, McPeek, & Keller, 2004; Van der Stigchel, Heeman, & Nijboer, 2012; Van der Stigchel, Mulckhuyse, & Theeuwes, 2009; Van der Stigchel et al., 2011). This seems to suggest that saccade averaging can occur for elements presented further apart. In these studies, however, the saccade landing distribution was not analyzed in detail as a function of the distance between the target and the distractor. For instance, it remains unclear whether these shifts of saccade endpoint truly represent a form of saccade averaging – in other words, whether the majority of eye movements were directed in between the two elements – or whether the distribution of saccade endpoints was bimodal. The aim of the present study is to provide such an analysis.

In Experiment 1, participants had to execute a saccade to a single target, which was accompanied by a distractor in the majority of the trials. This distractor was presented at various distances from the target, ranging from 12.5° to 30° in polar coordinates. This set-up allowed us to investigate whether there is indeed a restricted region in which saccade averaging is the dominant response. Furthermore, we could analyze whether saccade averaging decreases linearly or whether there is an abrupt shift from a unimodal to a bimodal distribution of saccade endpoints.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Eleven naive individuals (20–29 years old; 2 male) participated in the experiment. All had normal or corrected-to-normal visual acuity. Informed consent was obtained prior to the study in accordance with the guidelines of the Helsinki Declaration.

2.1.2. Apparatus

Participants performed the experiment in a sound-attenuated setting, viewing a display monitor from a distance of 65 cm. Eye movements were recorded by an Eyelink1000 system (desktop system; SR Research Ltd., Canada), an infra-red video-based eye tracker that has a 1000 Hz temporal resolution and a spatial resolution of 0.01°. The participant's head was stabilized with a chin rest, and an infrared remote tracking system compensated for any residual head motion. The left eye was monitored. An eye movement was considered as a saccade when either eye velocity exceeded 35°/s or eye acceleration exceeded 9500°/s^2.

2.1.3. Stimuli and procedure

Participants viewed a display containing a grey cross (1.0 × 1.0°) on a black background in the centre of the display, which was used as fixation point. The fixation cross remained on the screen during the entire trial. After a random interval of 400–900 ms, the target element was presented (a grey cross of .83 × .83°). The distance from the central fixation point to the target was 7.7°. The target could be positioned on one of four axes (polar coordinates: 45°, 135°, 225°, 315°). In 75% of the trials, an additional, distractor circle (.83° diameter) was presented on the same imaginary circle around the central fixation point as the target and was presented 12.5°, 15°, 17.5°, 20°, 22.5°, 25°, 27.5°, 30° either 'clockwise' or 'anticlockwise' from the target (in polar coordinates). For instance, if the target was presented at 45° and the distractor was presented at the shortest distance, the distractor was either presented at 32.5° or 57.5°. The target display was presented for 1500 ms. Afterwards all objects were removed from the display. The possible target–distractor configurations are represented in Fig. 1.

Participants were instructed to fixate on the central fixation point and to move their eyes to the target as quickly as possible after it was displayed on the monitor. Each session started with a nine-point grid calibration procedure. In addition, simultaneously fixating the central fixation point and pressing the space bar checked whether fixation was still accurately recorded by the eye tracker. The sequence of trials was randomized. The experiment consisted of 1024 experimental trials and 32 practice trials.

2.2. Data analysis

2.2.1. Saccade endpoint

Saccadic landing position was analyzed by computing the angle between the target and the landing position. The target was used as a null reference. Trials were only taken into account when the saccade landed in the quadrant of the target stimulus and its angle was not larger than 2.5 standard deviations from the mean

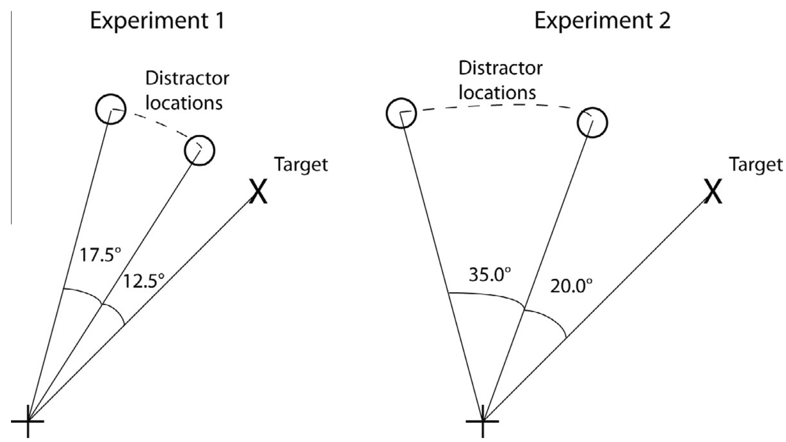

Fig. 1. An overview of the possible distances at which the distractor could be presented in Experiment 1 (left side) and Experiment 2 (right side).

of the relevant condition for that particular participant. Every first saccade with an amplitude larger than 2° was taken into account.

Eye movements sometimes portrayed a small drift from fixation at the start of the saccade. Since this influences the relative position of the stimuli in relation to the start of the saccade, the deviation score was calculated relative to the actual starting point of the saccade. This means that the deviation score was computed as the difference between the angle of the starting position and the landing position and the angle between the starting position and the target. Trials in which the saccade was initiated more than 1.78° (in visual degrees) away from the fixation point were removed from the analyses, as they were considered inaccurate fixations. The mean drift for all included trials was 0.74° (st. dev. = 0.36°).

To investigate whether the endpoint distribution was unimodal or bimodal, the endpoint distribution of each condition was compared to a constructed bimodal or a unimodal distribution (see Fig. 2). For these analyses, all saccades of all participants were collapsed and the values for the no-distractor condition were scaled to include the same number of trials as the conditions in which a distractor was presented. For the unimodal distribution, the fit of the no-distractor condition was stretched with respect to the distance between target and distractor (with 12.5° as a reference) and placed on the centre between target and distractor. For the bimodal condition, the fit of the no distractor condition was divided by two and placed on the location of the target and the distractor. These distributions were subsequently made proportional to the percentage of saccades landing on the target and the distractor (defined as landing within 10° of target and distractor). These two distributions were then combined, as is illustrated in Fig. 2. For some participants, the number of eye movements landing on the distractor were too little to determine a reliable bimodal fit (especially for some conditions in Experiment 2). Therefore, these analyses were not performed on an individual subjects level, but collapsed over all participants.

To compute which conditions showed a unimodal distribution and which conditions a bimodal distribution, we calculated the sum of squares for each condition with respect to the unimodal or bimodal distribution. The sum of squares is the sum of squared residuals, a residual being the difference between the observed value and the value of the constructed distributions.

2.2.2. Saccade latency

Saccade latency was defined as the interval between target onset and the initiation of the saccadic eye movement. Trials with a saccadic latency lower than 80 ms (anticipatory saccades) or higher than 600 ms (too slow saccades) were excluded from all analyses. For saccade latencies, an ANOVA was run with Condition (9 levels: no distractor, and the eight possible distractor distances) as a factor.

2.3. Results

The exclusion criteria led to a loss of 9.8% of trials; the majority of these were trials in which the saccade landing position was not appropriate.

2.3.1. Saccade endpoint

In the condition in which no distractor was presented, the endpoint deviation with respect to the target location was on average 4.41° (st. dev. = 0.89°). See also Fig. 2 for the overall endpoint distribution of the no-distractor condition.

When the mean value of the baseline condition was subtracted from the mean values of the conditions in which a distractor was presented, an ANOVA with Condition (the eight possible distractor distances) as a factor revealed a main effect, $F(7,70) = 41.90$; $p < .0001$. Planned comparisons revealed a significant linear contrast, $p < .0001$. As can be seen in Fig. 3a, this contrast indicates that saccade deviation increased with increasing distance between target and distractor. This finding reveals that the mean saccade endpoint was more shifted away from the target when the distance between target and distractor was larger. The various endpoint distributions are represented in Fig. 4. In this figure, it can clearly be seen that the endpoint distribution becomes broader with increasing distance between target and distractor. Furthermore, the distribution tends to always peak between distractor and target irrespective of the distractor–target distance.

When comparing the saccade deviation for trials in which the distractor was presented towards or away from the horizontal meridian, there was no main effect of Distractor Direction (towards vs. away), $F(1,10) = 1.25$; $p = .29$ and no interaction between Distractor Direction and Condition, $F(1,10) = 1.22$; $p = .30$.

Because the distance between target and distractor differed between the different conditions, the amount of saccade averaging cannot be compared directly. To compute whether the number of saccades landing in between target and distractor was similar across conditions in which a distractor was presented, we computed the saccade deviation as a proportion (0 being the target, 0.5 the location in between target and distractor and 1 the location of the distractor). This way, we corrected for the differences in distance between the various conditions. No main effect was observed, $F < 1$, indicating that the absolute global effect did not differ between conditions (see Fig. 3b).

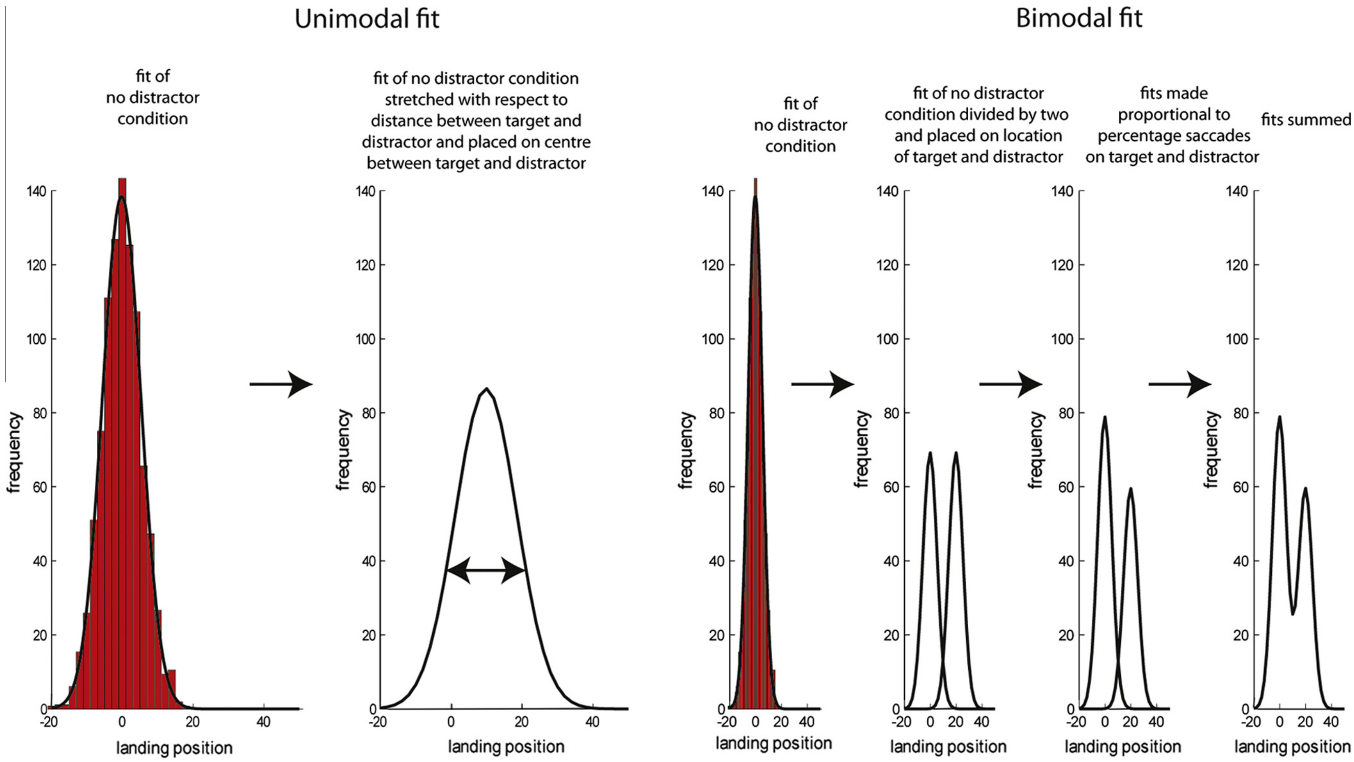

Fig. 2. Illustration of the computation of the unimodal and bimodal distributions. For the unimodal distribution, the fit of the no-distractor condition was stretched with respect to the distance between target and distractor (with 12.5° as a reference) and placed on the centre between target and distractor. For the bimodal distribution, the fit of the no distractor condition was divided by two and placed on the location of the target and the distractor. These distributions were subsequently made proportional to the percentage of saccades landing on the target and the distractor. These two distributions were then combined. Note that the values for the no-distractor condition were scaled to include the same number of trials as the conditions in which a distractor was presented. For this illustration, the 20° condition was taken as an example.

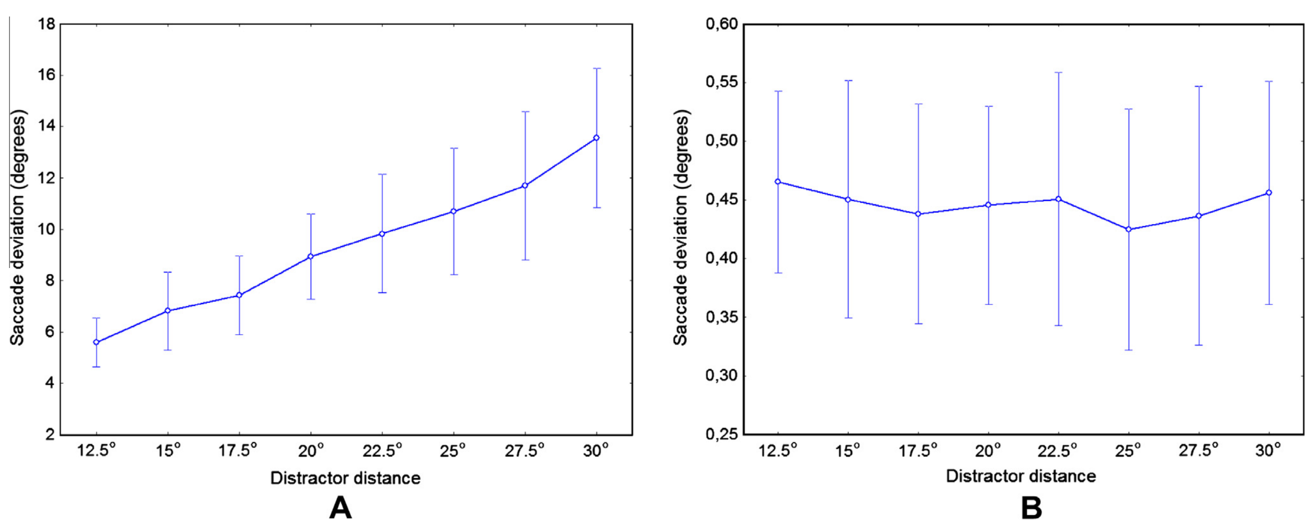

Fig. 3. (A) Saccade deviation with respect to the no-distractor condition for the various distances tested in Experiment 1. Error bars represent 95% confidence intervals. (B) Saccade deviation corrected for the differences in distance between the conditions. All deviation values were normalized to a value between 0 and 1. Error bars represent 95% confidence intervals.

With respect to the fit to the constructed unimodal or bimodal distributions, Fig. 4 shows that the endpoint distributions of each condition clearly resemble the constructed unimodal distribution. This was also evident from the sum of squares for the unimodal and bimodal distributions: for each condition the sum of squares of the bimodal distribution was minimally four times higher than the sum of squares of the unimodal distribution (mean bimodal = 20,811; st. dev. = 4954; mean unimodal = 2235; st. dev. = 904).

As explained in the Methods section, the unimodal distribution was constructed by stretching the no distractor condition with respect to the distance between the target and distractor. When this stretching was not applied, the sum of squares was eight times higher than the stretched unimodal distribution (mean = 18,533; st. dev. = 15,103), indicating that this stretching is crucial to acquire a good fit with the unimodal distribution.

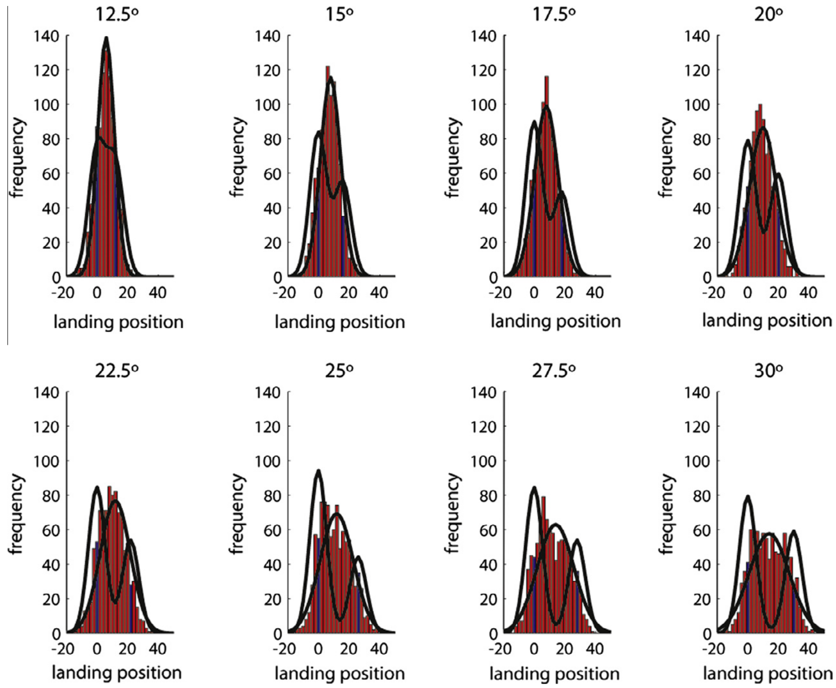

Fig. 4. Distribution plots of the endpoints for the different conditions in Experiment 1. The location of the target and the distractor are indicated by vertical bars. The unimodal and bimodal distributions, as illustrated in Fig. 2, are plotted on top of the distribution plots of the observed endpoints.

2.3.2. Saccade latency

An ANOVA on saccade latency showed a main effect of Condition, $F(8,80) = 8.09$; $p < .0001$. Planned comparisons revealed a significant linear contrast, $p < .0001$, indicating that saccade latency increased with increasing distance between target and distractor. This effect was also observed when the no-distractor condition was not included in the analyses. In the condition in which no distractor was presented, saccade latencies were longer than in the conditions in which a distractor was presented, $t(10) = 4.47$; $p < .01$, see Fig. 5.

2.4. Discussion Experiment 1

The results of Experiment 1 clearly indicated saccade averaging at all possible distances between the target and the distractor. Compared to the no distractor condition, the distribution of saccade endpoints was shifted towards the location of the distractor for each possible distance. As can be seen in Fig. 4, all distributions were unimodal with the majority of eye movements directed to a location in between the target and the distractor. Moreover, when corrected for the differences in distance between

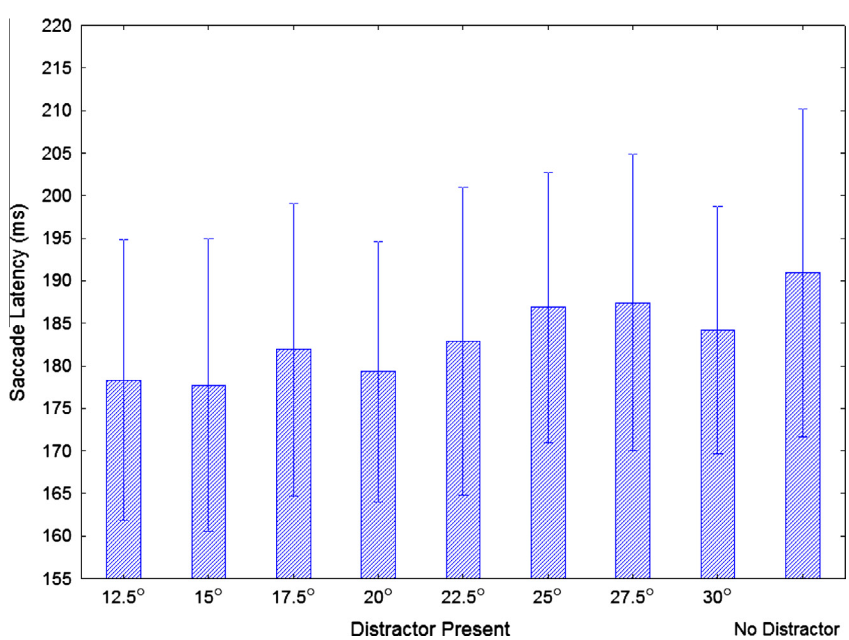

Fig. 5. Saccade latencies for the different conditions in Experiment 1. Error bars represent 95% confidence intervals.

the conditions, saccade averaging was equally strong for all conditions.

With respect to saccade latency, Experiment 1 indicated a decrease in reaction time when a distractor was presented compared to the no-distractor condition (see also, Godijn & Theeuwes, 2002). This is consistent with the idea that saccade averaging is associated with a decrease in saccade latency, as predicted by models which include the local spread of excitatory activity (for a review, see Casteau & Vitu, 2012). Especially when the distance between target and distractor is short, the combination of the visual signals of the target and the distractor might result in a signal that is stronger than the visual signal when no distractor is presented. This stronger visual signal might subsequently result in shorter latencies. Although the decrease in saccade latency when compared to the no-distractor condition was strongest for the shortest distances between target and distractor, latencies in all conditions were shorter than the no-distractor condition.

On the basis of the distances tested in Experiment 1, there does not appear to be a restricted zone in which saccade averaging is observed. It should be noted, however, that the range in the present experiment was quite limited (until 30°) which might have obscured such a zone beyond the tested distances. To this end, we performed a second experiment in which the longest distance was 55°. Except for this manipulation, the experiment was similar to Experiment 1. This experiment allowed us to answer the same questions as in Experiment 1, but now for more remote distances.

3. Experiment 2

3.1. Methods

3.1.1. Participants

Twelve naive individuals (20–29 years old; 2 male) participated in the experiment.

3.1.2. Apparatus, stimuli, procedure and analysis

The experimental set-up was similar to Experiment 1, except that the distractor was presented 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55° either 'clockwise' or 'anticlockwise' from the target (in polar coordinates); see Fig. 1.

Because the distance between target and distractor was larger than in Experiment 1, trial inclusion with respect to saccade endpoint was different from Experiment 1. Trials were only taken into account when the saccade landed within 7.2° of either target or distractor and its angle was not larger than 2.5 standard deviations from the mean of the relevant condition for that particular participant.

3.2. Results

The exclusion criteria led to a loss of 8.3% of trials; the majority of these were trials in which the saccade landing position was not appropriate.

3.2.1. Saccade endpoint

In the condition in which no distractor was presented, the endpoint deviation with respect to the target location was on average 4.91° (st. dev. = 1.58°).

When observing the endpoint distribution in Fig. 6, it can easily be seen that the endpoint distribution becomes broader with increasing distance between target and distractor. In contrast to Experiment 1, however, the distributions appear clearly to be bimodal in the conditions in which the distance between target and distractor is largest. In these conditions, the number of averaging saccades appears to decrease and the saccade appears to land either on the target or on the distractor. Because the distributions of saccade endpoints were clearly bimodal in some conditions, we could not analyze saccade deviation using an ANOVA.

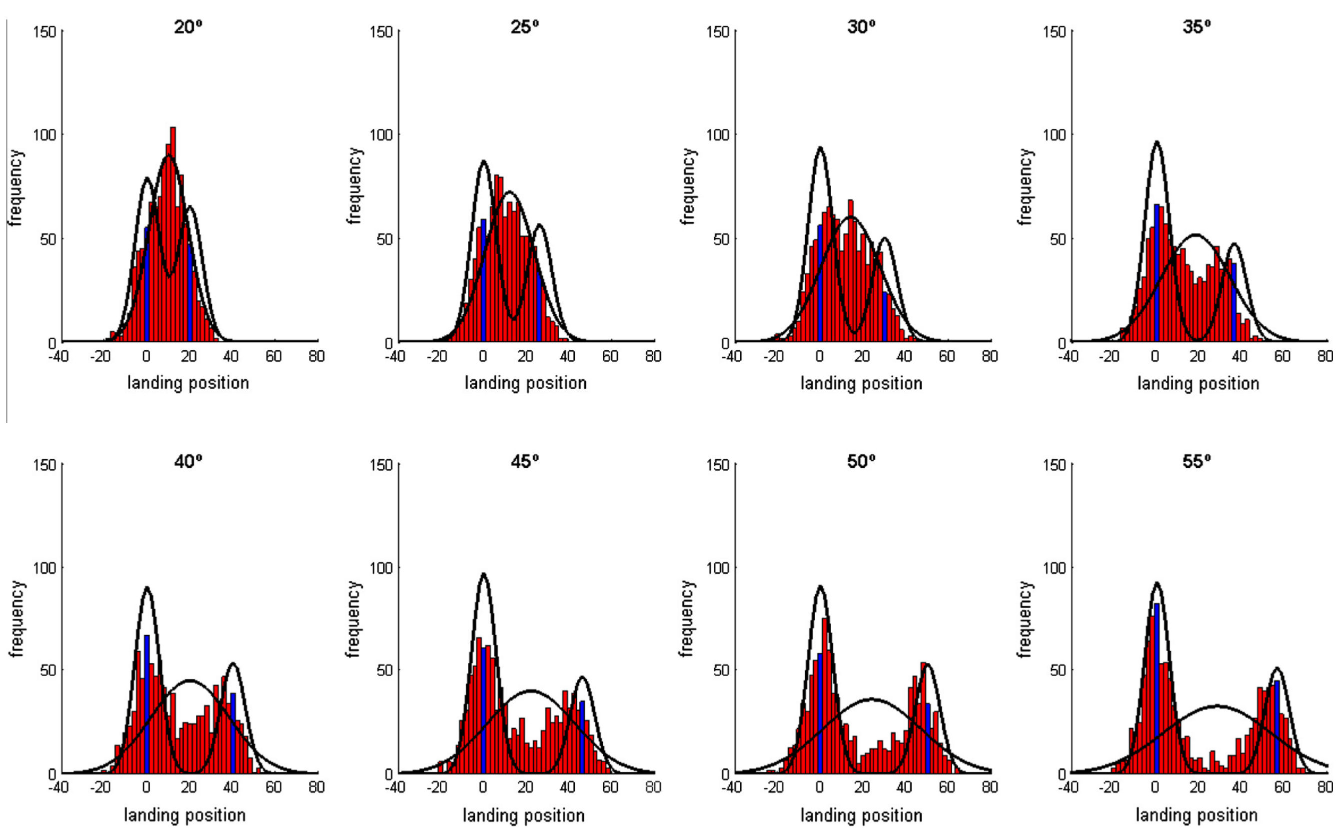

Fig. 6. Distribution plots of the endpoints for the different conditions in Experiment 2. The location of the target and the distractor are indicated by vertical bars.

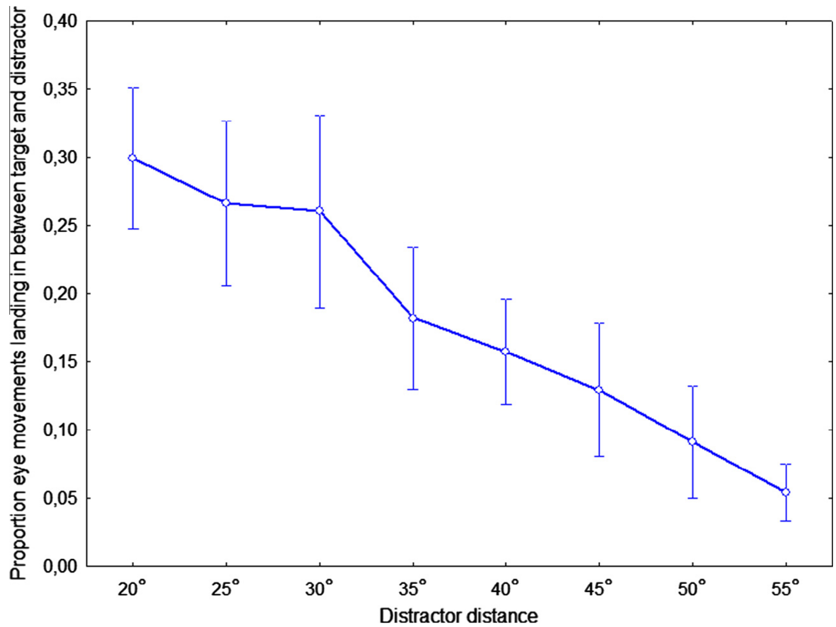

Fig. 7. Proportion of trials landing in the area in between the target and the distractor; the distance was divided in three equal parts and this analyses focused on the central part. Error bars represent 95% confidence intervals.

To investigate whether the proportion of eye movements landing in between the target and the distractor decreased, we divided the distance between target and distractor into three equally sized parts and compared, for each condition, the proportion eye movements landing in the middle part (see Fig. 7). A main effect was observed, $F(7,77) = 38.42$; $p < .0001$, explained by a strong linear trend ($p < .0001$). There was a strong trend for a lower amount of eye movements falling in between target and distractor when the distance between target and distractor is increasing.

With respect to the fit to the constructed unimodal or bimodal distribution, Fig. 6 shows that the endpoint distributions of the condition with a short distance between target and distractor is unimodal, whereas it is bimodal when the distance is larger. This was also evident from the sum of squares for the unimodal and bimodal distributions which can be observed in Fig. 8: for distances up to 35°, the sum of squares was lower for the unimodal distribution, whereas for distances larger than 45°, the sum of squares was clearly lower for the bimodal distribution. Similar to Experiment 1, the fit to a non-stretched unimodal endpoint distribution was 7.45 higher than to a stretched unimodal endpoint distribution.

3.2.2. Saccade latency

An ANOVA on saccade latency indicated a main effect of Condition, $F(8,88) = 12.13$; $p < .0001$. Planned comparisons revealed a significant linear contrast, $p < .0001$, indicating that saccade latency increased with increasing distance between target and distractor. Overall, however, there was no difference in saccade latency between the conditions in which a distractor was presented

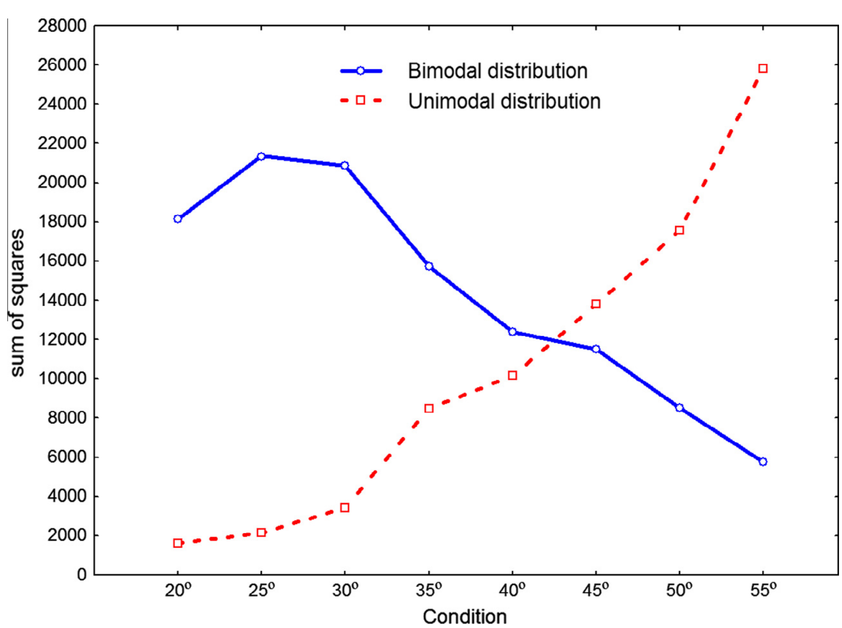

Fig. 8. Sum of squares of the observed endpoint distribution with the constructed unimodal and bimodal distributions.

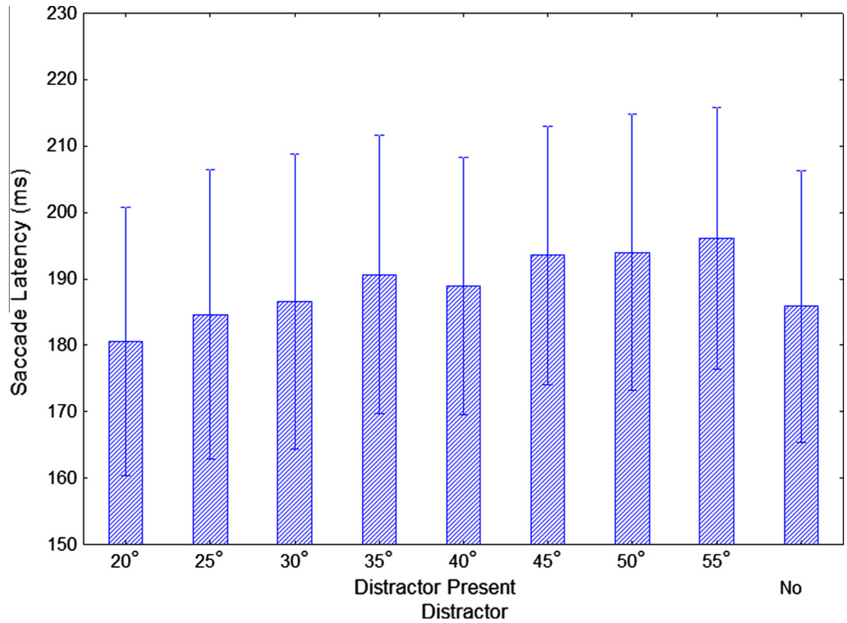

Fig. 9. Saccade latencies for the different conditions in Experiment 2. Error bars represent 95% confidence intervals.

and the condition in which no distractor was presented, $t(11) = 2.05$; $p = .07$, see Fig. 9. Analyses showed that saccade latencies were longer than in the no-distractor condition when the distance between target and distractor was largest. When corrected for multiple comparisons, only the condition in which the distance between target and distractor was 50° and 55° differed significantly from the no-distractor condition ($p < .05$).

3.3. Discussion Experiment 2

In this second experiment, more remote distances were tested compared to Experiment 1. When the distributions were examined in detail, it was apparent that almost no saccade averaging occurred when target and distractor were presented more than 45° in polar coordinates apart. When the distance between target and distractor was largest (55°), the distribution was clearly bimodal; eye movements were only initiated either towards the target or towards the distractor. An analysis examining specifically the saccades landing in between the target and distractor indicated that the number of these saccades decreased linearly with increasing distance between target and distractor.

Some of the tested distances were also used in Experiment 1. The results for these conditions were similar in both experiments, highlighting the robustness of these effects.

With respect to saccade latencies, a remote distractor effect was observed for the more remote distances in that saccade latencies were longer for the conditions in which a distractor was presented compared to the no-distractor condition. These findings are in line with the findings of Walker et al. (1997) who showed that the remote distractor effect was observed outside the zone in which saccade averaging was observed. Also in this experiment, the remote distractor effect was strongest for the distances in which no saccade averaging was observed.

4. General discussion

The aim of the present study was to systematically investigate the influence of the distance between a target and a distractor on the averaging of saccade programs. The results of the experiments confirmed the restricted region in which saccade averaging has been claimed to occur by showing that saccade averaging was only present up to a certain distance between target and distractor. In Experiment 1, in which only a limited range of distances was tested (up to 30° polar coordinates), saccade averaging was observed for all eight tested distances, with a unimodal distribution for all conditions. The location of the distractor, towards or away from the horizontal meridian, did not influence saccade averaging. In Experiment 2, in which more remote distances were tested, saccade averaging was only observed for the distances up to 35° in polar coordinates. Beyond this distance, the endpoint distribution was bimodal, with saccades landing either on the target or on the distractor. For even more remote distances between target and distractor, almost no eye movement landed in the region in between the two stimuli.

Although several previous studies have made claims about the effect of the distance between target and distractor on saccade averaging on the basis of the mean saccade endpoint (Van der Stigchel, Mulckhuyse, & Theeuwes, 2009; Van der Stigchel et al., 2011; Walker et al., 1997), the present study examined the endpoint distributions in detail and concluded whether saccade averaging occurred on the basis of the shape of the distribution (i.e. unimodal or bimodal). We would like to argue that a genuine global effect is observed when the endpoint distribution is unimodal with its peak position in between the two stimuli. Based on this analysis, the present study indicated that such a genuine global effect was only observed until the distance was around 35°.

The unimodal distribution observed for the shorter distances is interesting, given that participants received a specific task instruction to fixate on the target and ignore the distractor. Because the peak of the distribution was not positioned on the target location, this clearly illustrates that this task instruction was overridden by the averaging of the saccade programs. It can therefore be concluded that, in the current study, top-down information was not able to influence the oculomotor competition, except when the distance between the two stimuli was larger than around 35°. It therefore appears that top-down information is almost completely absent when the target and distractor are presented in close proximity. When the distance was larger, top-down information had a stronger influence on the oculomotor selection process, resulting in a larger proportion of saccades landing near the target. The finding that the distribution was bimodal indicates that there were still a subset of trials in which the saccade was erroneously directed to the distractor (also known as 'capture saccades', Theeuwes et al., 1998). In these trials, the distractor was not successfully rejected and won the competition for oculomotor selection due to its strong bottom-up visual signal.

Results further indicated that there is no strict border for the presence of saccade averaging, but that the transition from a unimodal to a bimodal endpoint distribution is linear: the proportion of saccades landing in between the target and distractor decreased linearly for the distances higher than 30° until almost no saccades landed in between target and distractor when the distance was 55°. This is interesting as it indicates that for these larger distances, oculomotor selection is not an all-or-none process (i.e. either the distractor or the target wins the competition). Whereas saccades that land on the distractor reflect trials in which the distractor is erroneously selected as the target location of the eye movement, these averaging saccades reflect the still unresolved competition between target and distractor. In essence, these averaging saccades are a reflection of a complete absence of top-down information as the response is purely based on visual information. Therefore, although our results indicate that there is only a limited area in the saccade map in which saccade averaging occurs, averaging saccades can still be observed for distances higher than 30°. The probability of averaging saccades for these distances decreases linearly with the distance between target and distractor, however.

It has to be noted that the values observed in our study might not be generalized to all other experimental lay-outs. For instance, we used a fixed distance from fixation at which both elements were presented. Due to the cortical magnification factor, elements presented closer to fixation might elicit a stronger response than elements presented further away (Casteau & Vitu, 2009). This stronger response might result in different values than the ones reported in this study. The same holds for other factors that might influence the strength of one of two signals, like stimulus size or conspicuity.

For the more remote distances between target and distractor, the results for saccade latencies were consistent with the remote distractor effect (Walker et al., 1997); latencies were longer when a distractor was presented compared to the no-distractor condition. Similar to the results of Walker et al. (1997), this increase in latency was observed only in the conditions in which saccade averaging was mostly absent. This dissociation between the remote distractor effect and saccade averaging is in line with the idea of lateral interactions in the saccade map: saccade averaging is the result of a local spread of excitatory activity, whereas the increase in saccade latency has been explained by the inhibitory connections in the saccade map between remote locations (Olivier, Dorris, & Munoz, 1999). For the shorter distances, in which saccade averaging was strongest, we observed a decrease in saccade latency when compared to the no-distractor condition. This decrease might be explained by the 'averaged' strong signal associated with averaged saccade programs and is in line with the prediction of lateral-interaction models that saccade latencies will be reduced due to the quick build-up of activity at the location in between target and distractor. Interestingly, this decrease in saccade latency has been reported in a few previous studies only (for a review, see Casteau & Vitu, 2012). Furthermore, this decrease was also not observed in a recent computational model of the global effect (Meeter, Van der Stigchel, & Theeuwes, 2010), although this model did not include short-range excitation in the saccade map and top-down inhibition was implemented as the mechanism to select the target and reject the distractor.

Besides models of lateral interactions in the saccade map, an alternative model of oculomotor target selection assumes competitive interactions between a fixation and a move system (Findlay & Walker, 1999). Whereas the function of the fixation system is to keep the eyes still, the move system enables the movement of the eyes towards the periphery. Saccade latency is determined by the time until activity of the fixation system lowers to a certain threshold. The remote distractor effect then results from enhanced fixation activity, as activity in the fixation system is assumed to be enhanced by an additional stimulus. Based on the neurophysiology of the oculomotor system, Casteau and Vitu (2012) recently argued that such a model would predict that the crucial variable to modulate the remote distractor effect is the relative eccentricity of the stimuli and not the distance between the two stimuli (see also Walker et al., 1997). Our results are not consistent with this suggestion, as we showed that a robust remote distractor effect was only observed in the conditions in which the distance between target and distractor was largest. As the eccentricity of the two stimuli was held constant, our experiment was not designed to disentangle between these two types of models of oculomotor selection. Future studies will therefore need to resolve which factors determine these modulations in saccade latency (see, Casteau & Vitu, 2012).

The results of the present study indicate that the weighted average resulting in saccade averaging is based on a restricted region in the motor map. This motor map is generally assumed to be located in the intermediate layers of the superior colliculus (SC) (Schall, 1991; Sparks & Hartwich-Young, 1989). This mid-brain structure contains a retinotopically-organized map in which neural activity is correlated with target selection (McPeek & Keller, 2004; Wurtz, Goldberg, & Robinson, 1980). The SC integrates input from many cortical areas such as the Frontal Eye Fields (FEF), the Supplementary Eye Fields (SEF), the posterior parietal cortex and occipital visual areas (Munoz, 2002) and sends the outcome of this integration process to the brainstem premotor circuitry where the eye movement is programmed (Moschovakis, 1996). With respect to saccade averaging, neurophysiological recordings in the SC have shown that the saccade endpoint for averaging saccades is a result of the integration of the visual signals in the SC (Edelman & Keller, 1998). The current study suggests that this integration process only seems to include signals that are located with a restricted region in the SC. This idea is in line with various models that have accounted for the global effect (Findlay & Walker, 1999; Meeter, Van der Stigchel, & Theeuwes, 2010; Van Opstal & Van Gisbergen, 1989).

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